EQL Memo No. 26

ENVIRONMENTAL QUALITY LABORATORY RESEARCH REPORT 1985–1987

EQL MEMORANDUM NO. 26
July 1988

Environmental Quality Laboratory

CALIFORNIA INSTITUTE OF TECHNOLOGY

Pasadena, California 91125

RESEARCH REPORT
1985 – 1987

ENVIRONMENTAL QUALITY LABORATORY

California Institute of Technology

Pasadena, California 91125

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JULY 1988

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AN INTRODUCTION TO EQL

The Environmental Quality Laboratory at Caltech is a center for research on large-scale systems problems of natural resources and environmental quality. The principal areas of investigation at EQL are:

1. Air quality management.
2. Water resources and water quality management.
3. Control of hazardous substances in the environment.
4. Energy policy, including regulation, conservation and energy–environment tradeoffs.
5. Resources policy (other than energy); residuals management.

EQL research includes technical assessments, computer modeling, studies of environmental control options, policy analyses, and research on important components of the large–scale systems. Field work is also undertaken at EQL, some in collaboration with other organizations, to provide critical data needed for evaluation of systems concepts and models.

EQL's objectives are as follows:

1. *To do systematic studies of environmental and resources problems.* The results of these studies, including the clarification of policy alternatives, are communicated to decision–makers in government and industry, to the research community, and to the public. As an organization, EQL refrains from advocating particular policies, but seeks to point out the implications of the various policy alternatives.

2. *To contribute to the education and training of people in these areas* through involvement of predoctoral students, postdoctoral fellows, and visiting faculty members in EQL activities. This educational effort is just as important as the results of the studies themselves, and should make lasting contributions to the nation's ability to solve its environmental and resources problems.

The work at EQL goes beyond the usual academic research in that it tries to organize and develop the knowledge necessary to clarify society's alternatives by integrating relevant disciplines. EQL works on solving problems of specific localities when there is a strong element of public interest or educational value, or the concepts and results are applicable to other places.

The research of EQL during this period was done under the supervision of faculty members in Environmental Engineering Science, Chemical Engineering, and Social Science.

This research report covers the period from October 1985 through September 1987. The publications listed under the individual project descriptions are the new ones for the reporting period. To obtain a complete list of EQL publications or other information, and to order publications, please write or telephone: Publications Secretary, EQL 105–96, Caltech, Pasadena, Ca 91125; telephone 818/356–4167; FAX 818/356–2940.

ENVIRONMENTAL QUALITY LABORATORY

PROFESSIONAL STAFF, 1985 – 1987

Norman H. Brooks, Director

		Dates *
Norman H. Brooks	James Irvine Professor of Environmental and Civil Engineering; Director, EQL	
Glen R. Cass	Associate Professor of Environmental Engineering	
Jeffrey A. Dubin	Associate Professor of Economics	
Theresa Fall	Research Assistant	2/78–10/87
Richard C. Flagan	Professor of Environmental Engineering Science and Mechanical Engineering	
Panagiotis G. Georgopoulos	Senior Research Engineer	3/86–
Michael R. Hoffmann	Professor of Environmental Engineering Science	
Robert C.Y. Koh	Senior Research Associate in Environmental Engineering Science	
Mary P. Ligocki	Research Scientist	3/87–
E. John List	Professor of Environmental Engineering Science	
Gregory R. Markowski	Consultant	
Monica A. Mazurek	Research Fellow in Environmental Engineering Science	2/86–
Kenneth F. McCue	Scientist	
Richard D. McKelvey	Professor of Political Science	
Nibuo Mimura	Visiting Associate in Environmental Engineering Science; Fulbright Scholar from Ibaraki University, Japan	9/87–

*Month and year of residence at EQL are shown only for those who were not in residence for the whole period 10/85 – 9/87.

James J. Morgan	Professor of Environmental Engineering Science; Vice President for Student Affairs	
R. Talbot Page	Senior Research Associate in Economics	11/79–12/85
Charles R. Plott	Professor of Economics	
James P. Quirk	Professor of Economics	1987
Geoffrey S. Rothwell	Research Fellow in Economics	8/85–9/86
Lynn Salmon	Research Assistant	9/86–
John H. Seinfeld	Louis E. Nohl Professor and Executive Officer, Chemical Engineering	
Fredrick H. Shair	Professor of Chemical Engineering	
Paul A. Solomon	Scientist	
Bernhard Wehrli	Visiting Associate	9/87–
Paul Whitmore	Scientist	11/84–8/86
Louis L. Wilde	Professor of Economics and Executive Officer, Social Sciences	

SUPPORT STAFF, 1985 – 1987

Luisa Betterton	Senior Administrative Secretary	1/87–6/87
Elaine Campbell	Senior Administrative Secretary	12/85–5/86
Christina Conti	Senior Administrative Secretary	8/84–9/86
Dixie Fiedler	Senior Administrative Secretary	9/86–
Patricia Houseworth	Senior Administrative Secretary (part–time)	
Judith L. Kleiner	Administrative Secretary	12/86–2/87
Patricia Rankin	Assistant to the Director	
Nancy Tomer	Senior Drafter	

GRADUATE STUDENTS SUPPORTED#

BY EQL GRANTS AND CONTRACTS

1985–86		1986–87	
Name	Option*	Name	Option*
Collett, Jeffrey L.	EES	Boylan, Richard	SS
DiChristina, Thomas J.	EES	Collett, Jeffrey L.	EES
Fuhs–Huff, Susan E.	ME	Curlo, Eleonora	SS
Georgopoulos, Panagiotis	ChE	Elliott, Alexander	EES
Hildemann, Lynn	EES	Erel, Yigal	Geol
Huang, David	Che	Fuhs–Huff, Susan E.	ME
Kormann, Claudius	EES	Hildemann, Lynn	EES
Larson, Susan M.	EES	Horrell, Robin S.	ChE
Liang, Liyuan	EES	Larson, Susan M.	EES
Nazaroff, William W.	EES	Liang, Liyuan	EES
Olson, Terese	EES	Mau, Russell	EES
Pilinis, Christodoulos	EES	Munger, J. William	EES
Scott, Michael	EES	Nazaroff, William W.	EES
Sima, Hong	EES	Paulson, Suzanne	EES
Tan, Guofu	SS	Pilinis, Christodoulos	EES
Wang, Rueen–Fang T.	EES	Schlautman, Mark A.	EES
		Scott, Michael	EES
		Wang, Rueen–Fang T.	EES

* ChE = Chemical Engineering
EES = Environmental Engineering Science
Geol = Geology
ME = Mechanical Engineering
SS = Social Science

In some cases only partial support was provided by EQL

DOCTORAL THESES COMPLETED

1985 – 87

Name	Field	Faculty Adviser
Panagiotis G. Georgopoulous	ChE	J.H. Seinfeld
Mathematical Studies of Photochemical Air Pollution		
H. Andrew Gray	EES	G.R. Cass
Control of Atmospheric Fine Primary Carbon Particle Concentrations		
Jeffrey Banks	SS	J. Ledyard/R. McKelvey
Signaling Games: Theory and Applications		
Susan Mary Larson	EES	G.R. Cass
A Study of Summer Midday Low–Visibility Events in the Los Angeles Area		

SPONSORS AND DONORS

The staff and students of EQL gratefully acknowledge the support of the following research sponsors and donors for fiscal years 1986 and 1987:

Government Sponsored Projects

Local

South Coast Air Quality Management District

State

California Air Resources Board

Federal

Environmental Protection Agency
National Science Foundation
National Aeronautics and Space Administration (through the Jet Propulsion Laboratory).

Private Sources

Discretionary Funds – General

Bechtel Foundation
General Electric Foundation
General Motors
The William and Flora Hewlett Foundation
Andrew W. Mellon Foundation
Southern California Edison Company
Texaco

Discretionary Funds – Specific Program Areas

ARCO
Exxon Education Foundation
Andrew W. Mellon Foundation
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Sponsored Research Projects

J. Paul Getty Conservation Institute
AeroVironment, Inc.
Coordinating Research Council
Southern California Edison Company

SUMMARIES OF EQL RESEARCH PROJECTS

1985–87

A. AIR QUALITY MANAGEMENT

B. WATER RESOURCES AND WATER QUALITY

B. WATER RESOURCES AND WATER QUALITY (Cont'd.)

C. RISK ASSESSMENT

D. RESOURCES AND REGULATION

A. AIR QUALITY MANAGEMENT

DEVELOPMENT OF A COMPREHENSIVE ATMOSPHERIC MODEL FOR AIR POLLUTION AEROSOLS

Investigators: Christodoulos Pilinis*, John H. Seinfeld

Support: State of California Air Resources Board

Within the next several years, critical and expensive decisions will be made in California and other states concerning the levels of hydrocarbon, NO_x, and perhaps SO_2 control required to progress toward meeting existing and anticipated State and Federal air quality standards for ozone, NO_2, particles less than 10 microns in diameter (PM–10), visibility and reducing acidic deposition. Decisions on how much emission reduction is required to achieve specified improvements in air quality can only be made based on a model relating emissions to ambient air quality. Prediction of PM–10, fine particles, visibility and acidic species requires a model capable of relating gaseous and particulate emissions to gaseous acidic substances and particulate sulfate, nitrate, organics, and elemental carbon, ammonium–water and metal–and–soil compound concentrations.

Under support of the California Air Resources Board, we are currently developing such a model. The airshed submodel is a computation carried out within each grid cell of the full Caltech photochemical air quality model, updated at each time step akin to the chemical kinetics. The model will include treatment of liquid phase chemistry, the physics influencing the dynamics of particle size distributions, and parameterization of dry deposition.

Publications:

P. Saxena, A. B. Hudischewskyj, C. Seigneur and J. H. Seinfeld, "A Comparative Study of Equilibrium Approaches to the Chemical Characterization of Secondary Aerosols," Atmospheric Environment, v. 20, pp. 1471–1483, 1986.

C. Pilinis, J. H. Seinfeld, C. Seigneur, "Mathematical Modeling of the Dynamics of Multicomponent Atmospheric Aerosols," Atmospheric Environment, v. 21, pp. 943–955, 1987.

C. Pilinis, J. H. Seinfeld, "Continued Development of a General Equilibrium Model for Inorganic Multicomponent Atmospheric Aerosols," Atmospheric Environment, v. 21, pp. 2453–2466, 1987.

*Graduate Student, Environmental Engineering Science

MATHEMATICAL MODELING OF CHEMICALLY-REACTING PLUMES

Investigators: Panagiotis Georgopoulos*, John H. Seinfeld

Support: State of California Air Resources Board, William and Flora Hewlett Foundation

A new comprehensive model for chemically-reacting plumes has been developed. The model accounts for the effects of incomplete turbulent macro– and micro–mixing on chemical reactions between plume and ambient constituents. This "turbulent reacting plume model" is modular in nature, allowing for the use of different levels of approximation of the phenomena involved. The core of the model consists of the evolution equations for reaction progress variables appropriate for evolving spatially-varying systems. The equations estimate the interaction of mixing and chemical reaction, and require input parameters characterizing internal plume behavior such as relative dispersion and fine-scale plume segregation. The model offers the opportunity for calculating the evolution of chemically-reacting species in real atmospheric plumes and will be applied to the problem of predicting NO_2 levels downwind of strong point sources of nitric oxide.

Publications:

P. G. Georgopoulos, J. H. Seinfeld, "Instantaneous Concentration Fluctuations in Point Source Plumes," AICHE Journal, v. 32, pp. 1642–1654, 1987.

P. G. Georgopoulos, J. H. Seinfeld, "Mathematical Modeling of Turbulent Reacting Plumes: I. General Theory and Model Formulation," Atmospheric Environment, v. 20, pp. 1791–1807, 1986.

P. G. Georgopoulos, J. H. Seinfeld, "Mathematical Modeling of Turbulent Reacting Plumes: II. Application to the NO–NO_2–O_3 System," Atmospheric Environment, v. 20, pp. 1809–1818, 1986.

P. G. Georgopoulos, J. H. Seinfeld, "Estimation of Relative Dispersion Parameters from Atmospheric Turbulence Spectra," Atmospheric Environment, v. 22, pp. 31–41, 1988.

*Senior Research Engineer

DEVELOPMENT OF STRATEGIES FOR VISIBILITY IMPROVEMENT USING AN IMAGE PROCESSING-BASED VISIBILITY MODEL

Investigators: Susan Larson*, Kenneth McCue, Mary Ligocki, Kevin J. Hussey**, Frederick Luce**, Jeff Hall**, Glen R. Cass

Support: State of California Air Resources Board, William and Flora Hewlett Foundation, Gifts to the Environmental Quality Laboratory, National Aeronautics and Space Administration

Light scattering calculations based on pollutant properties measured during intense pollution episodes can be used to add haze to the foreground of clear sky pictures by image processing techniques. The ability of these light scattering and absorption calculations to accurately reproduce the visual effects that occur during smog episodes is being verified by comparing the synthetic smog images to digitized photos of actual high pollution events. The completed visibility model is being used as part of a systematic investigation of emission control strategies which could be used to achieve a deliberate improvement in summer midday low–visibility conditions in the Los Angeles area.

Publications:

S. M. Larson, G. R. Cass, K. J. Hussey, F. Luce, "Verification of Image Processing–Based Visibility Models," Environmental Science and Technology, v. 22, pp. 629–637, 1988.

S. M. Larson, "A Study of Summer Midday Low–Visibility Events in the Los Angeles Area," Ph.D. Thesis, California Institute of Technology, 1988.

*Graduate Student, Environmental Engineering Science
**Image Processing Laboratory, JPL

CONTROL OF ATMOSPHERIC AEROSOL NITRATE AND NITRIC ACID CONCENTRATIONS

Investigators: Armistead G. Russell*, Kenneth F. McCue, Glen R. Cass

Support: State of California Air Resources Board, Gifts to the Environmental Quality Laboratory

A grid–based air quality model has been used to study the effect of specific emission control measures on atmospheric NO_2, total inorganic nitrate (TN), HNO_3, aerosol nitrate, PAN, NH_3 and ozone concentrations in the Los Angeles area. NO_x and reactive hydrocarbon (RHC) emission reductions of up to 61% and 37%, respectively, were examined. NO_2 and TN concentration reductions in excess of 50% averaged over 20 monitoring sites would be achieved at the highest level of emission control studied. The distribution of TN air quality improvements between HNO_3 and aerosol nitrate would be affected by the NH_3 emission rate of the NO_x control technologies employed. Peak 1–hr O_3 concentrations at many sites in the eastern portion of the air basin studied would decline by more than 25% at the highest NO_x and RHC control levels studied, with the final increment of NO_x control alone capable of producing O_3 concentration improvements at locations with the highest O_3 concentrations.

Publications:

A. G. Russell, K. F. McCue, G. R. Cass, "Mathematical Modeling of the Formation of Nitrogen–Containing Air Pollutants: I. Evaluation of an Eulerian Photochemical Model," Environmental Science and Technology, v. 22, pp. 263–271, 1988.

A. G. Russell, K. F. McCue, G. R. Cass, "Mathematical Modeling of the Formation of Nitrogen–Containing Pollutants: II. Evaluation of the Effect of Emission Controls," Environmental Science and Technology, 1988, in press.

A. G. Russell, G. R. Cass, J. H. Seinfeld, "On Some Aspects of Nighttime Atmospheric Chemistry," Environmental Science and Technology, v. 20, pp. 1167–1172, 1986.

*Assistant Professor, Mechanical Engineering Department, Carnegie–Mellon University

ACQUISITION OF ACID VAPOR AND AEROSOL CONCENTRATION DATA IN THE SOUTH COAST AIR BASIN

Investigators: Paul Solomon, Theresa Fall, Lynn Salmon, Susan Larson*, Philip Lin**, Harvey Liu**, Mike Jones**, Frank Vasquez**, David Cole**, Sandra Blumhorst**, Nancy Drehwing**, Doug Gray**, Betsy Andrews**, Glen R. Cass

Support: State of California Air Resources Board, South Coast Air Quality Management District

A field experiment has been conducted to measure the spatial and temporal concentration distribution of gas phase acids (HNO_3, HCl, HBr, HF, formic acid) and related particulate phase species in the southern California atmosphere. Atmospheric nitric acid concentrations were found to peak in the summer months, with maximum 24–hour average concentrations in the vicinity of 10 ppb. Conversion of nitric acid to aerosol phase nitrates was found to be a dominant factor in the production of high airborne particle concentrations in the eastern portion of the Los Angeles basin. Peak 24–hour average PM_{10} concentrations (particulate matter in sizes below 10 μm aerodynamic diameter) reached 299 gm^{-3} in the Riverside area during October 1986, a factor of 2 higher than the Federal PM_{10} air quality standard, and 6 times higher than allowed by California air quality standards. More than 100 gm^{-3} of that peak aerosol burden consisted of aerosol nitrate plus associated ammonium ion. Data collected during this experiment are being used to devise air pollution abatement plans for PM_{10} in the Los Angeles area.

Publications:

P. A. Solomon, S. M. Larson, T. Fall, and G. R. Cass, "Basinwide Nitric Acid and Related Species Concentrations Observed During the Claremont Nitrogen Species Comparison Study," Atmospheric Environment, in press.

W. R. Pierson, W. W. Brachaczek, S. M. Japar, G. R. Cass, P. A. Solomon, "Dry Deposition and Dew Chemistry in Claremont, California, During the 1985 Nitrogen Species Methods Comparison Study," Atmospheric Environment, in press.

S. V. Hering, D. R. Lawson, et al., "The Nitric Acid Shootout: Field Comparison of Methods for Nitric Acid", Atmospheric Environment, in press.

P. A. Solomon, T. Fall, L. G. Salmon, G. R. Cass, et al., Acquisition of Acid Vapor and Aerosol Concentration Data for Use in Dry Deposition Studies in the South Coast Air Basin, Final Report to the State of California Air Resources Board, forthcoming.

*Graduate Student, Environmental Engineering Science
**Undergraduate Student

CHARACTERIZATION OF ORGANIC AEROSOLS IN SOURCE EMISSIONS AND IN AMBIENT AIR

Investigators: Lynn Hildemann*, Monica Mazurek, Gregory R. Markowski, Bernd Simoneit**, Glen R. Cass

Support: U.S. Environmental Protection Agency, Gifts to the Environmental Quality Laboratory

The relationship between the chemical composition of organic compounds in source emissions and the composition of organics observed in atmospheric particulate matter is being investigated. The objectives are to identify the major sources of organic particulate matter, to accurately characterize the kinds of organic aerosols being emitted by various source types, and to investigate the extent to which secondary organic aerosols are produced by chemical reactions in the atmosphere. Particulate emissions from a wide range of major aerosol source types have been collected using a dilution stack sampling system specially constructed to simulate the atmospheric condensation and aging processes normally experienced within a stack plume containing organic air pollutants. Analysis of these samples by high–resolution gas chromatography and computerized gas chromatography/mass spectrometry is being used to define the characteristic organic compound signature for each source type. A method for identifying the relative importance of different emission sources in contributing to the organic aerosol species loading present in the atmosphere will be tested by comparing these source signatures to the chemical composition of ambient particulate matter samples using a fluid mechanically–based atmospheric transport model.

Publications:

M. A. Mazurek, B. R. T. Simoneit, G. R. Cass and H. A. Gray, "Quantitative High–Resolution Gas Chromatography/Mass Spectrometry Analysis of Carbonaceous Fine Aerosol Particles," International Journal of Environmental Analytical Chemistry, v. 29, pp. 119–139, 1987.

L. M. Hildemann, G. R. Cass, G. R. Markowski, "A Dilution Stack Sampler for Collection of Organic Aerosol Emissions: Design, Characterization, and Field Tests," Aerosol Science and Technology, in press.

M. A. Mazurek, B. R. T. Simoneit, G. R. Cass, "Interpretation of High–Resolution Gas Chromatography and High–Resolution Gas Chromatography/Mass Spectrometry Data Acquired from Atmospheric Organic Aerosol Samples," Aerosol Science and Technology, in press.

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*Graduate Student, Environmental Engineering Science
**Professor, Environmental Geochemistry Group, College of Oceanography, Oregon State University

CHARACTERIZATION AND CONTROL OF ATMOSPHERIC CARBON PARTICLE CONCENTRATIONS

Investigators: H. Andrew Gray*, Shohreh Gharib**, James J. Huntzicker***, Glen R. Cass

Support: State of California Air Resources Board

Light absorption by elemental carbon particles plays a major role in urban visibility problems. A multi–year study designed to identify efficient approaches for control of atmospheric carbon particle concentrations has been completed. An eleven-station air monitoring network was constructed and operated in the Los Angeles area to define current elemental and organic carbon particle concentrations. A mathematical model of the relationship between aerosol carbon emission sources and resultant regional air quality was assembled and tested against observations made during the ambient sampling program. Emissions from diesel engines were found to be responsible for a large portion of the atmospheric fine carbon particle concentrations in the Los Angeles atmosphere, and control of diesel engine emissions is an important component of the least expensive approach available for aerosol carbon air quality improvement. It was found that basin–wide primary aerosol carbon concentrations could be reduced by about 35% at a cost of about 102 million dollars per year.

Publication:

H. A. Gray, "Control of Atmospheric Fine Primary Carbon Particle Concentrations," Ph.D. thesis, California Institute of Technology, 1986. Also published as Environmental Quality Laboratory Report 23, 328 pp.

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*Graduate Student, Environmental Engineering Science
**Staff Scientist (formerly)
***Acting President, Oregon Graduate Center, Beaverton, OR.

CONTROL OF THE DRY DEPOSITION OF NITROGEN-CONTAINING AIR POLLUTANTS

Investigators: Armistead G. Russell*, Kenneth F. McCue, Glen R. Cass

Support: State of California Air Resources Board

An improved mathematical model for computing the dry deposition flux of nitrogen–containing air pollutants is being developed. The model will be used to study the effect of candidate emission control strategies on acid dry deposition in southern California.

As yet there are no written reports available for distribution.

*Assistant Professor, Mechanical Engineering Department, Carnegie–Mellon University

STUDIES OF VISIBILITY-REDUCING ORGANIC AEROSOLS IN THE DESERT SOUTHWESTERN UNITED STATES (SCENES-ORIGIN OF ORGANICS STUDY)

Investigators: Monica Mazurek, Bernd R. T. Simoneit*, Glen R. Cass

Support: The Electric Power Research Institute, AeroVironment, Inc.

Organic particulate matter is a major contributor to the visibility–reducing aerosol present in the vicinity of the national parks in the desert southwestern United States. Identification of the emission sources that contribute to this organic aerosol is being pursued. High resolution gas chromatography and gas chromatography/mass spectrometry analyses of aerosol samples taken by the SCENES air monitoring network are being undertaken to search for organic molecules that act as tracers for particulate emission source types. It has been found that wood smoke and plant waxes are two of the significant contributors to the organic aerosol samples studied.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

*Professor, Organic Geochemistry Group, College of Oceanography, Oregon State University

PROTECTION OF WORKS OF ART FROM DAMAGE DUE TO PHOTOCHEMICAL SMOG

Investigators: Paul M. Whitmore, William W. Nazaroff*, C. Pam DeMoor**, Cynthia Wittman**, Kaitlin Drisko**, James R. Druzik***, Daniel Grosjean****, Glen R. Cass

Support: J. Paul Getty Conservation Institute

The fading of pigments is a major hazard to works of art. Work in our laboratories has shown that a number of widely-used artists' pigments are not ozone–fast, and will fade during a 95-day exposure to 0.40 ppm ozone in the absence of light. The extent of this ozone hazard to works of art has been assessed through examination of more than 150 organic pigment samples obtained from the Fogg Museum at Harvard. The chemistry of the attack of ozone on artists' pigments has been investigated via GC/MS analysis of the pigments and their reaction products.

The distribution of ozone and NO_2 concentrations in the indoor atmosphere of museums in southern California has been assessed via a series of field experiments. Mathematical models for the behavior of pollutants inside museums and archives have been developed and tested. Strategies for protecting works of art from damage due to air pollutants are being developed, including selection of pollutant–resistant pigments, pigment reformulation, pollutant removal via ventilation system redesign, encapsulation of works of art, and the use of protective binders and coatings.

Publications:

W. W. Nazaroff, G. R. Cass, "Mathematical Modelling of Chemically–Reactive Pollutants in Indoor Air," Environmental Science and Technology, v. 20, pp. 924–934, 1986.

P. M. Whitmore, G. R. Cass, J. Druzik, "Ozone Fading of Traditional Natural Organic Colorants on Paper," Journal of the American Institute for Conservation, v. 26, pp. 45–58 1987.

K. Drisko, G. R. Cass, P. M. Whitmore, J. R. Druzik, "Fading of Artists' Pigments due to Atmospheric Ozone," in Winer Berichte uber Naturwissenschaft in Der Kunst, Bd 2/3, 1985/86, ed. A. Vendl, B. Pichler, and J. Weber, Vienna:Verlag ORAC, 1986.

P. M. Whitmore, G. R. Cass, "The Ozone Fading of Traditional Japanese Colorants," Studies in Conservation, v. 33, pp. 29–40, 1988.

*Graduate Student, Environmental Engineering Science
**Undergraduate Student
***Staff Member, J. Paul Getty Conservation Institute, Marina del Rey, Ca.
****Visiting Associate, Division of Chemistry and Chemical Engineering

D. Grosjean, P. M. Whitmore, C. P. DeMoor, G. R. Cass, "Fading of Alizarin and Related Artists' Pigments by Atmospheric Ozone: Reaction Products and Mechanisms," Environmental Science and Technology, v. 21, pp. 635–643, 1987.

D. Grosjean, P. M. Whitmore, G. R. Cass, J. R. Druzik, "Ozone Fading of Natural Organic Colorants: Mechanisms and Products of the Reaction of Ozone with Indigos," Environmental Science and Technology, v. 22, pp. 292–298, 1988.

PROTECTION OF WORKS OF ART FROM DAMAGE DUE TO AIRBORNE PARTICULATE MATTER

Investigators: William W. Nazaroff*, Mary Ligocki, Theresa Fall, Lynn Salmon, Mike Jones**, Harvey Liu**, Timothy Ma**, Glen R. Cass

Support: J. Paul Getty Conservation Institute

The soiling of works of art due to deposition of airborne particulate matter poses a major hazard to museum collections. Over long periods of time, dark deposits build up on the surfaces of paintings, sculpture and stone buildings, necessitating cleaning procedures that are both expensive and that pose some risk to the works themselves.

A study is underway designed to understand how to control or prevent this particle deposition problem. Airborne particle concentrations, size distributions and chemical composition measurements are being made inside and outside of five museums in the Los Angeles area. The flux of particles to interior surfaces also is being measured. These field experimental data are being used to test theoretical computer–based models that account for the size distribution and chemical composition of the indoor aerosol and the particle flux to surfaces. The completed indoor air quality model is being used to evaluate alternative procedures for controlling the particle deposition process.

Publication:

W. W. Nazaroff, G. R. Cass, "Particle Deposition from a Natural Convection Flow onto a Vertical Isothermal Flat Plate," Journal of Aerosol Science, v. 18, pp. 445–455, 1987.

*Graduate Student, Environmental Engineering Science
**Undergraduate Student

B. WATER RESOURCES AND WATER QUALITY

MODELING OF TRANSPORT AND FATE OF POLLUTANTS IN COASTAL WATER

Investigators: Robert C.Y. Koh, Miles Bogle, Siu C. Cheung

Support: National Oceanic and Atmospheric Administration, Andrew W. Mellon Foundation, William and Flora Hewlett Foundation

This study seeks to develop models for the estimation of transport and fate of pollutants from ocean wastewater outfalls. The overall transport phenomena, which combine to determine the physical fate of the pollutants, consist of several phases: (i) initial mixing which occurs in a time scale of minutes and a distance scale of a few kilometers; (ii) advective transport by ocean currents which occurs in a time scale of hours to a few days; and (iii) sedimentation of particles, which contain much of the hazardous substances in wastewater.

Two models are developed. One is a state–of–the–art model for the nearfield mixing processes. The second is a model for the advective transport and particulate sedimentation. Actual current meter data coupled with detailed local bathymetry are used to deduce both the deterministic and statistical aspects of the advective transport parameters for specific sites. These are then utilized via Monte Carlo simulation techniques to derive transport and depositional probabilities.

Publications:

S. C. Cheung, R. C. Y. Koh, "Modeling of Advective Transport and Turbulent Dispersion in Coastal Waters," Report to NOAA, 1985.

R. C. Y. Koh, "Shoreline Impact from Ocean Waste Discharges," ASCE Journal of Hydraulic Engineering, v. 114, pp. 361–376, 1988.

SETTLING CHARACTERISTICS OF DIGESTED SEWAGE SLUDGE PARTICLES

Investigators: Robert C.Y. Koh, Norman H. Brooks, Theresa R.F. Wang*

Support: Andrew W. Mellon Foundation, William and Flora Hewlett Foundation, National Oceanic and Atmospheric Administration, Sanitation Districts of Orange County, Sanitation Districts of Los Angeles County

An important parameter governing the fate of particles in digested sewage sludge discharged into the ocean is the fall velocity of the particles. Preliminary results in conventional settling column experiments show that the apparent fall velocity distributions depend not only on the specific sample (i.e., sampling time and location) but also on initial mixing in the experimental procedures.

Both sedimentation and coagulation contribute to the observed settling column experimental results. A conceptual model including sedimentation, coagulation, and vertical diffusion was postulated to provide an alternate interpretation of observed results which showed through comparison with experiments that the often assumed second order coagulation rate is not the general case and the interpretation of experimental data via a simple fall velocity distribution is not correct.

New experiments were designed to overcome this inherent difficulty. Coagulation and sedimentation are forced to occur sequentially in a coagulating reactor (flocculator) and a settling chamber. Very high dilution ratios (10000:1) are used to suppress further coagulation in a settling chamber. An in–line holographic camera system is used to provide a direct method of measuring size, shape and velocity of sludge particles. Results have been obtained for both sludge and effluent particles. These data (i) are consistent with Stokes settling; (ii) suggest that the particles have high void ratio; and (iii) do not reveal any substantial difference between sludge and effluent particles.

Publications:

T. R. Wang, R. C. Y. Koh, N. H. Brooks, "Interpretation of Settling Column Measurements of Sludge," Proceedings of the Fifth International Ocean Disposal Symposium, 10–14, September 1984, Corvallis, Oregon, in press.

T. R. Wang, "Laboratory Analysis of Settling Velocities of Wastewater Particles in Seawater Using Holography," Ph.D. Thesis, California Institute of Technology, 1988, 265 pp.

*Graduate Student, Environmental Engineering Science

RESEARCH PLAN FOR EXPERIMENTAL DEEP OCEAN SLUDGE DISPOSAL FOR ORANGE COUNTY

Investigators: Norman H. Brooks, Robert C.Y. Koh, Robert G. Arnold*

Support: Sanitation Districts of Orange County, National Oceanic and Atmospheric Administration, Andrew W. Mellon Foundation, William and Flora Hewlett Foundation

The discharge of sewage sludge into the ocean via an outfall is not now permitted. Nonetheless the option may in some cases be more desirable than other disposal options (to land or incineration). Previous studies by EQL have (i) assessed ocean alternatives for the southern California area, and (ii) developed a research plan to show what could be learned with a full–scale experimental sludge discharge of 150 dry tons/day of sludge by the County Sanitation Districts of Orange County into deep water (over 1000 feet). A revision of the original research plan is in progress.

National policy for sludge disposal has taken into account the findings of the above-mentioned EQL studies with regard to ocean disposal of sludge. The 1987 amendments to the Clean Water Act specifically enable EPA to grant a research permit to Orange County for the deep water sludge outfall and the conduct of the developed research plan.

Publications:

N. H. Brooks, R. G. Arnold, R. C. Y. Koh, G. A. Jackson, W. K. Faisst, "Deep Ocean Disposal of Sewage Sludge Off Orange County, California: A Research Plan," EQL Report No. 21, second edition in preparation, 1988.

N. H. Brooks, R. G. Arnold, R. C. Y. Koh, G. A. Jackson, W. K. Faisst, "A Research Plan for Deep–Ocean Disposal of Sewage Sludge off Orange County, California" in Oceanic Processes in Marine Pollution, Volume 2, Physicochemical Processes and Wastes in the Ocean, edited by T. P. O'Connor, W. V. Burt, I. W. Duedall, published by Robert E. Krieger, Malabar, Florida, pp. 99–115, 1987.

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INFLUENCES ON KELP GROWTH BY A PCB COMPOUND

Investigators: Margaret Carter*, David E. James**, Steven L. Manley, Wheeler J. North

Support: SURF Funds, EQL Funds, Kelco Company, ARCO

Usage of the polychlorobenzene (PCB) class of organic compounds was phased out several years ago because of demonstrated toxicities by the compounds to plants and animals. Unfortunately, PCBs have been utilized for so long and natural degradation processes are so slow, that trace quantities of these toxicants persist in our environment and occur in our various waste discharges. Research on effects of PCBs on microscopic stages in the life cycle of giant kelp Macrocystis (a dominant and ecologically–important seaweed) was initiated as a summer project under the SURF+ program. A very clear–cut toxic response was found, which has been confirmed by subsequent studies. From this preliminary work it appears that PCBs might have a significant ecological effect in coastal waters of southern California and that kelp microscopic stages may have good potential as a bioassay organism with a short response time. The study has continued and been expanded to a Ph.D. thesis research program, under support from Pacific Gas and Electric Company and the Keck Foundation.

Publication:

D. E. James, S. L. Manley, M. C. Carter, W. J. North, "Effects of PCBs and Hydrazine on Life Processes in Microscopic Stages of Selected Brown Seaweeds," Proceedings of the 12th International Seaweed Symposium, W. Junk, Netherlands, in press.

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FOG, CLOUD, AND RAIN CHEMISTRY

Investigators: J. William Munger*, Jeff Collett*, Bruce Daube**, Daniel J. Jacob*, Jed M. Waldman*, and Michael R. Hoffmann

Support: California Air Resources Board

We have established that fog and cloudwater in southern California are consistently acidic (pH 1.7 to 4.0). With the aid of automated collectors, we have been able to determine the spatial and temporal variation of fog/cloud chemistry within large areas of fog occurrence. Areas that have been studied include the Los Angeles coastal area, where previous work suggests that the highest acidities occur, and the Riverside–San Bernardino area, which is subject to fog during the height of the smog season. We have maintained extensive sampling networks in the southern San Joaquin Valley and the Santa Barbara Channel. The limited ventilation documented in previous tracer studies of the Channel and presence of fog and high humidity there suggest that rapid S(IV) (i.e. total SO_2 aqueous) oxidation in the Channel could result in highly acidic fog. pH values in the vicinity of the Santa Barbara Channel have been found to range from 1.9 to 4.5. In conjunction with fog and stratus cloud sampling, we have performed more detailed measurements of deposition during fog.

In addition to determining the major ionic, acidic, and trace–metallic content of fog and cloudwater, we have determined the role of carboxylic and sulfonic acids in fog acidification. Our previous work has shown the covariance of very high levels of S(IV) and formaldehyde, suggesting the presence of aldehyde–S(IV) adducts (i.e. sulfonic acids). We have determined quantitatively the higher aldehydes and have identified unequivocally sulfonic acids formed by reaction of S(IV) with aldehydes.

In Los Angeles, storm systems originate over the Pacific Ocean and have little or no contact with polluted air masses until they reach the South Coast Air Basin. Two major types of Pacific cyclonic storms can be identified. The first type (Type I) has a major trajectory characterized by a southerly flow up the coast which has been preceded by a pre–frontal condition that moves in from the SE. During this type of storm, high clouds form over the inversion layer and the underlying pre–frontal flow. As precipitation begins below–cloud scavenging of the polluted air mass will be an important mechanism for the accumulation of chemical components within rain. During an event of this type, the concentrations of chemical components will be initially high. As the storm matures the inversion layer is broken and the storm becomes convective in nature. The second type (Type II) of storm moves in to the South Coast Air Basin during a period with no low-level stability; this type storm will be of a convective nature from the beginning. We anticipate that a Type II storm will show lower concentrations of chemical components in rainwater initially.

In addition to the Pacific cyclonic storms, which provide the majority of precipitation in the SCAB, stratus clouds may thicken sufficiently to produce light drizzle. This drizzle exhibits very high concentrations of H^+, NH_4^+, NO_3^-, and SO_4^{2-}, but is only a minor contributor to the total precipitation budget in the basin. Stratus rain events occurred within a developed marine layer. The ionic concentrations of these rains were significantly higher than for the storm events.

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The cloud >> drizzle hierarchy of solute concentration also reflects the relationship between droplet size and dilution. The growth of non–freezing cloud droplets to a size with appreciable sedimentation velocity occurs solely by condensation of water vapor for sizes below 50 μm diameter; subsequently both coalescence and condensation lead to drizzle (0.2 to 0.5 mm) and raindrop (>0.5 mm) sizes depending upon the intensity of vertical motion.

Stratus rain events led to solute deposition which was clearly disproportionate to the water flux. Stratus rain accounted for only ~ 1 % of the measured rainfall at Henninger Flats while it accounted for nearly 20 % of the total deposition of H^+, NO_3^-, and SO_4^{2-} in less than 16 mm of precipitation. Na^+ and Cl^- were substantially less enhanced in stratus rain than winter storm events. The winter storms responsible for most of the precipitation form over the eastern Pacific Ocean. They are more effective at generating and transporting sea salt aerosol due to their greater convective activity. For stratus rain, the enhancement of H^+, and NO_3^- was greatest, and for NH_4^+ and SO_4^{2-} it was somewhat less. The difference in nitrate/sulfate ratios for stratus (1.4) versus storm events is a further indication of the meteorological and seasonal variation in SO_2 and NO_x oxidation and transport.

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J. M. Waldman, J. W. Munger, D. J. Jacob, and M. R. Hoffmann, "A Field Study of Pollutant Deposition in Radiation Fog," submitted to Atmos. Environ., 1988.

J. M. Waldman, J. W. Munger, D. J. Jacob, and M. R. Hoffmann, "Chemical Characterization of Stratus Cloudwater and its Role as a Vector for Pollutant Deposition in a Los Angeles Pine Forest," Tellus, 37B, pp. 91–108, 1985.

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DYNAMICS OF ARSENIC AND SELENIUM IN WATER/SEDIMENT SYSTEMS

Investigators: Michael J. Scott*, James J. Morgan

Support: Andrew W. Mellon Foundation

Arsenic and selenium are naturally–occurring, non–metallic elements with complex chemical and biological behavior in aquatic environments. Contamination of Kesterson Reservoir (California) is a well–known example of selenium accumulation in ecosystem water/sediments. Arsenic and selenium can both exist as inorganic oxyanions (e.g., arsenite, arsenate; selenite, selenate) in water. Adsorption to oxide mineral surfaces, e.g., iron oxides or aluminosilicates, is believed to be an important process regulating the aqueous concentrations of arsenic and selenium species in water. Thermodynamic information predicts that arsenate and selenate, AsO_4^{3-} and SeO_4^{2-}, respectively, are the stable forms in oxygen–containing waters, while arsenite and selenite, AsO_3^{3-}, and SeO_3^{2-}, respectively, are stable in anoxic waters.

Environmental observations for these elements strongly suggest that chemical transformations between reduced and oxidized forms are quite slow, that many systems are far from equilibrium, and that kinetic information is needed, in addition to thermodynamic data, to predict actual behavior in natural systems. Rates of heterogeneous system redox reactions need to be established for selenium and arsenic for representative mineral surfaces under temperature, pH and dissolved mineral conditions representative of natural systems. This research addresses several key questions; among them, what chemical reactions control the geochemical distribution of arsenic and selenium in contaminated aquatic systems, and what is the role of metal oxide surfaces in the rates of transformation under environmental conditions? Laboratory experiments, modelled on conditions in representative water/sediment systems which are experiencing selenium or arsenic pollution, are being carried out to answer these questions.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

*Graduate Student, Environmental Engineering Science

SORPTION KINETICS IN THE MODELING OF HYDROPHOBIC ORGANIC TRANSPORT IN GROUNDWATERS

Investigators: Mark Schlautman*, James J. Morgan, Norman H. Brooks

Support: William and Flora Hewlett Foundation, Andrew W. Mellon Foundation

The understanding of sorption processes is an important key to describing the fate of hydrophobic organic pollutants in groundwaters because sorption can significantly alter the physical transport and chemical reactivity of these compounds. Transport and reaction will determine whether methods utilized in the remediation of polluted aquifers can be successful. Existing models attempt to describe the sorption process on fixed soil particles. The models simulate sorption as either an equilibrium process or nonequilibrium process, coupled with the classical convective–dispersive transport equation. Attempts are being made to determine the conditions under which results from these two types of models converge. This information will be useful in remediation efforts since the amount of equilibrium data and correlations vastly exceeds the kinetic data for sorption processes. In addition, the importance of sorption to mobile, colloid–sized particles is another aspect to be examined. Colloid transport may be a significant mechanism for hydrophobic organic pollutants in an aquifer. Little information is available on the role of particle transport in the fate of these compounds. A comprehensive groundwater model incorporating both solute and particle transport and sorption onto migrating particles as well as onto the soil matrix is required to adequately predict the movement of organics at certain polluted sites.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

*Graduate Student, Environmental Engineering Science

SURFACE CHEMISTRY OF IRON OXIDE (HEMATITE, α–Fe_2O_3) COLLOIDAL PARTICLES IN AQUEOUS SYSTEMS

Investigators: Liyuan Liang* and James J. Morgan

Support: Jessie Smith Noyes Foundation, Andrew W. Mellon Foundation

Particles in the colloidal size range are of great interest in environmental science and engineering. Aqueous oxide particles have high specific surface areas, adsorb ions and molecules from water, and may remain kinetically stable in an aqueous phase with respect to coagulation. A key to understanding particle stability and coagulation is the surface chemistry of those solutes which strongly influence electrostatic forces between particles. Experiments using submicron hematite particles (α–Fe_2O_3, 75nm in diameter) reveal important features of coagulation dynamics through light scattering measurements, electrokinetic measurements of electrical charge on oxide particles, and equilibrium adsorption measurements for surface species. Acid–base titration data indicate that the zero–charge pH of colloidal hematite is 8.5, in agreement with eletrophoretic mobility measurements.

In the presence of non–specifically adsorbed ions (e.g., Na+), the coagulation of colloidal hematite is achieved mainly by compression of the diffuse ionic layer. Specifically adsorbed ions (e.g., phosphate) dramatically reduce surface charge of Fe_2O_3 particles. For inorganic solutes the order of effectiveness in achieving hematite coagulation is:

phosphate>sulphate>chloride

and

magnesium>calcium>sodium~potassium

Adsorption studies reveal that phthalate ions specifically adsorb, and that the process is due to carboxylic group bonding to the surface. Hematite coagulation rates in the presence of poly–aspartic acid (PAA) reveal that the polyelectrolyte is unusually effective in coagulation. Similar coagulation features are observed when naturally occurring organics (e.g., fulvic and humic acid from Suwannee River) are used. Adsorption of long–chain fatty acids (C_3 to C_{12}) can be interpreted in terms of the total energy contributed by specific chemical, electrostatic and hydrophobic interactions. Coagulation rates of hematite with respect to fatty acid concentration show systematic variations with chain length (hydrophobic effect). The results of the laboratory findings prove useful in explaining field observations on iron particle behavior in lakes, rivers and estuaries.

Publication:

L. Liang, "Effects of Surface Chemistry on Kinetics of Coagulation of Submicron Iron Oxide Particles (α–Fe_2O_3) in Water," Ph.D. Thesis, California Institute of Technology, 1988, 156 pp.

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MECHANISMS OF MINERAL DISSOLUTION

Investigators: Bernhard Wehrli*, James J. Morgan

Support: Andrew W. Mellon Foundation, EAWAG (Swiss Federal Institute for Water Resources and Water Pollution Control)

Chemical weathering of minerals controls the neutralization of acid rain. As a consequence, the concentration of dissolved aluminum has risen in sensitive aquatic environments to toxic levels. Mechanistic models on a molecular scale are essential for a general understanding of the kinetics of weathering processes. The dissolution reaction involves a change in the first coordination sphere of metal ions — a fact which can be modelled in terms of lattice statistical nearest–neighbor relations. Monte Carlo simulations have been performed in order to clarify the interdependence between surface geometry and dissolution kinetics. The model predicts that the "roughness" of a dissolved oxide surface is a simple function of the activation energy of the process.

An experimental study on the dissolution of $Al_{13}0_4(OH)_{24}(OH2)_{12}{}^{7+}$is in progress. This polynuclear complex can be identified by ^{27}AL–NMR and serves as a structurally well-characterized model compound. The kinetic data will be used to test and calibrate our lattice statistical model. The results should close a gap in the knowledge on the kinetics of Al(III) in the aqueous environment.

This is a preliminary report of work in progress, and as yet no written reports are available for distribution.

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C. RISK ASSESSMENT

COMMON KNOWLEDGE IN MODELS OF INFORMATION AGGREGATION AND LEARNING

Investigators: Richard D. McKelvey and Talbot R. Page

Support: National Science Foundation

In this research, we are investigating the process by which information is utilized in situations where individuals have access to both private and public information. Consider a situation in which individual economic agents obtain private information about the likelihood of some event (such as the likelihood some chemical is toxic). The agents are then periodically required to make decisions based on their beliefs (like how much of the chemical to produce or sell), and some function of these decisions (like a market price) then becomes public information. In previous research, we found conditions which guarantee that individual economic agents in the above setting, starting with different private information about an event, will eventually come to share common beliefs about the likelihood of that event. The intention of this research is to investigate the extent to which our earlier results can be generalized, and to investigate the degree to which the game theoretic model underlying the analysis, which assumes a kind of super rationality on the part of the agents, is a good model of real behaviour. In this connection, we have done both theoretical work and experimental work. The research has potential applications to risk assessment, and to research and development in competitive industries.

Publications:

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RISK ASSESSMENT IN THE NUCLEAR POWER INDUSTRIES

Investigator: Jeffrey A. Dubin

Support: Exxon Education Foundation

Collaborative work with Professor Geoffrey Rothwell of Stanford University on risk assessment in the nuclear power industries has yielded two papers, "Preparing for the Improbable: Safety Incentives and the Price–Anderson Act," and "Risk and Reactor Safety Systems Adoptions."

Preparing for the Improbable . . .

The Price–Anderson Act requires commercial nuclear power plants to maintain (approximately) $660 million in off–site accident coverage through two forms of insurance: market–provided private insurance and self–insurance in the form of retrospective assessments of reactor owners. How do changes in retrospective assessments influence the safety incentives of nuclear reactor owners? It is found that increase in self–insurance premiums increase the incentive to install safety systems more quickly. However, a more important conclusion is that self–insurance premiums as a function of reactor riskiness, rather than equal payments by reactor owners, yield a higher level of safety than under the current law.

Risk and Reactor Safety System Adoptions

How do firms react to the risk of accidents that disable their industrial plant? This question is examined by modeling the electric utility's present–value maximizing decision to install reactor safety systems. The optimal adoption time is a function of the probability of a serious accident, the cost of the safety system, potential damages, and insurance premiums. An econometric version of the model is applied to the empirical evidence of implementing a computer–graphics warning system for nuclear reactors. It is found that: (1) owners of plants with higher equipment failures and lower bond ratings were quicker to adopt the safety system; (2) owners of larger plants were slower to adopt; and (3) the size of the population surrounding the plant, the state regulatory climate in which the reactor is operating, and the value of the initial plant investment had no influence on the speed of adoption.

Publications:

J. A. Dubin, G. S. Rothwell, "Preparing for the Improbable: Safety Incentives and the Price–Anderson Act," Caltech Social Science Working Paper No. 642, May, 1987, submitted to Social Science Journal.

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D. RESOURCES AND REGULATION

HOW MARKETS FOR IMPURE PUBLIC GOODS ORGANIZE: THE CASE OF HOUSEHOLD REFUSE COLLECTION

Investigator: Jeffrey A. Dubin

Support: Exxon Education Foundation

This study examines how markets for impure public goods organize within the context of household refuse collection. It is demonstrated that observed public choices of apparently inefficient forms of market organization embody rational behavior consistent with utility maximization where both rent–seeking interest groups and community preferences influence policy choices. The assessment of the relative efficiency of these choices is placed in a dynamic framework where initial market organization choice is allowed to influence eventual cost. The approach permits the separation of economic and political factors, and shows that significant economies of density exist in the market for refuse collection and to calculate the additional cost of collection associated with a community's ideological preferences.

Publication:

J. A. Dubin, P. Navarro, "How Markets for Impure Public Goods Organize: The Case of Household Refuse Collection," Journal of Law, Economics, and Organization, 1988, forthcoming.

THE DISTRIBUTIONAL EFFECTS OF THE FEDERAL ENERGY TAX ACT

Investigator: Jeffrey A. Dubin

Support: Exxon Education Foundation

This study, done in collaboration with Professor Steven E. Henson of Western Washington University, examines the distributional consequences of the tax credits implemented by the Federal Energy Tax Act of 1978. The distributional effects are of interest both for their own sake, and because they have implications for the cost–effectiveness of the credits. If rates of return to conservation are higher for individuals who consume less housing, as earlier evidence suggests, then conservation incentive programs can achieve larger benefits for a given cost if they are distributionally more progressive.

We explain the amount of credit claimed by taxpayers using a tobit model, in which credits claimed are a function of variables that affect the net benefit of weatherization. We estimate the model using data from the 1979 Taxpayer Compliance Measurement Program conducted by the Internal Revenue Service. We find that the credits claimed are significantly higher where winters are more severe, where energy prices are high or rising rapidly, and where individuals have higher incomes and spend more on housing.

Progressivity indices based on Lorenz–Gini measures of inequality reveal that the tax credits were somewhat regressive, even holding climate and energy prices constant. This suggests that the credits may have been ineffectively targeted. In addition, we find no evidence that the credits had a measurable incentive effect, suggesting that they have largely provided windfall gains to households who would have insulated anyway.

Publication:

J. A. Dubin, "The Distributional Effects of the Federal Energy Tax Act," Resources and Energy," 1988, forthcoming.